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Study of the B_s meson with forthcoming LHC data at CMS

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Abstract. A study of the properties of the B_s meson decays has been done using a full Monte Carlo simulation of the CMS detector. The CMS pixel detector allows a precise measurement of the B_s decay vertices which are displaced from the proton-proton interaction point. This facilitates a time dependent analysis of the angular correlations between the B_s decay products. In particular, the decay $B_s \to (J/\psi)\phi \to \mu^+\mu^-K^+K^-$ enables measurements of the width difference between heavy and light mass eigenstates. Furthermore, it permits a measurement of the CP violating phase ϕ_s which is sensitive to physics beyond the Standard Model.

Keywords: LHC, CMS, B_s meson
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INTRODUCTION

The Compact Muon Solenoid (CMS) is one of the multipurpose detectors at the Large Hadron Collider (LHC) at CERN. LHC is a pp collider with the designed center of mass energy of $\sqrt{s} = 14$ TeV. The CMS silicon tracker [1], closest detector to the interaction point, consists of 1440 silicon pixel and 15148 silicon strip detector modules. It is located, together with the electromagnetic and hadron calorimeters, inside a superconducting solenoidal magnet, which provides an axial field of 3.8 T. Outside of the solenoid is the muon system for identifying and triggering on muons and for their trajectory reconstruction in the magnet return yoke.

The pixel detector performance allows precise measurements of the B_s meson decay vertices, permitting to measure properties of two B_s weak eigenstates B_s^L and B_s^H such as differences between their widths ($\Delta\Gamma_s$) and masses (Δm_s). Moreover, the decay $B_s \to (J/\psi)\phi \to \mu^+\mu^-K^+K^-$ provides one of the best ways to determine the weak angle ϕ_s, where ϕ_s is the B_s^0 mixing phase angle (or twice the angle β_s) in the unitary triangle.

In the first section mixing in the neutral B_s system will be discussed, while the second section focuses on $B_s \to (J/\psi)\phi$ event reconstruction. Lastly, the prospective results for 1.3 fb^{-1} of integrated luminosity with full Monte Carlo simulation will be shown.

MIXING IN THE NEUTRAL B_s SYSTEM

The B_s meson (containing a $\bar{b}$ and an s quark) (Fig.1) oscillates into its anti particle $\bar{B}_s$ through weak interaction. By studying $B_s - \bar{B}_s$ mixing, it is possible to measure parameters, in particular Δm_s, $\Delta\Gamma_s$ and the CP violating phase ϕ_s [2]. CP violation in the $B_s - \bar{B}_s$ system is due to interference between decay and mixing.

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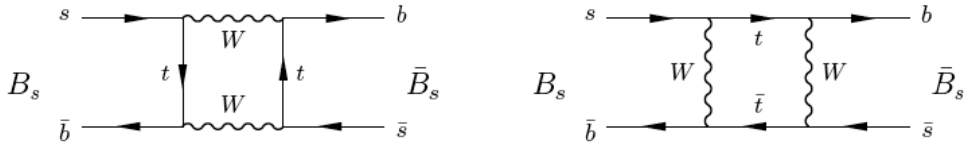

FIGURE 1. The Standard Model permits B_s mesons to change into $\bar{B}_s$ mesons and vice versa. These transitions lead to particle mixing

The time evolution of the B_s and $\bar{B}_s$ states can be described by the non-Hermitian Hamiltonian $\mathscr{H}$ which can be represented with 2×2 matrices

$$\mathscr{H} = M - \frac{i}{2}\Gamma \tag{1}$$

The relation between M, Γ and the mixing parameters is $\Delta m_s = 2[M_{12}]$ and $\Delta\Gamma_s = 2[\Gamma_{12}]$, where $\Delta\Gamma_s = \Gamma^H - \Gamma^L$ and $\Delta m_s = m_H - m_L$ and the two eigenstates with heavier and light mass eigenvalues are B_s^H and B_s^L, respectively.

According to the Standard Model the value for ϕ_s is -0.04 [3]. However, there are predictions for non-SM value for ϕ_s due to new physics beyond the SM. Recent results indicate that the B_s mixing amplitude deviates by more than 3σ from the Standard Model prediction [4].

$B_s \to (J/\psi)\phi \to \mu^+\mu^-K^+K^-$ DECAY CHANNEL RECONSTRUCTIONS

For the reconstruction of the decay channel, three dedicated trigger levels have been designed. They attempt a reconstruction of the $B_s \to (J/\psi)\phi$ decay chain [5].

A kinematic vertex fit is applied offline and a time-dependent angular analysis is performed to extract the width difference $\Delta\Gamma_s$.

To obtain a clean sample of $B_s \to (J/\psi)\phi \to \mu^+\mu^-K^+K^-$ events, the following cuts are applied: $p_T(\mu) > 3$ GeV/c, $P_T(J/\psi) > 4$ GeV/c, $\Delta m_{J/\psi} < 120$ MeV/c^2, and finally $p_T(K) > 0.8$ GeV/c, $p_T(J/\psi) > 1$ GeV/c, $\Delta m_\psi < 20$ MeV/c^2 and $p_T(B_s) > 5$ GeV/c, where $\Delta m_{J/\psi}$ and Δm_ϕ denotes the difference between the invariant mass of the reconstructed (J/ψ) and ϕ respectively, from the known (J/ψ) mass and ϕ mass, 3097 MeV/c^2 and 1019 MeV/c^2 each [6] .

The vertex fit is applied to the two muons tracks and the two kaons tracks, thus constraining the (J/ψ) mass at the same time and improving the resolution of the B_s invariant mass from σ = 34 MeV/c^2 to σ = 14 MeV/c^2 (Fig. 2).

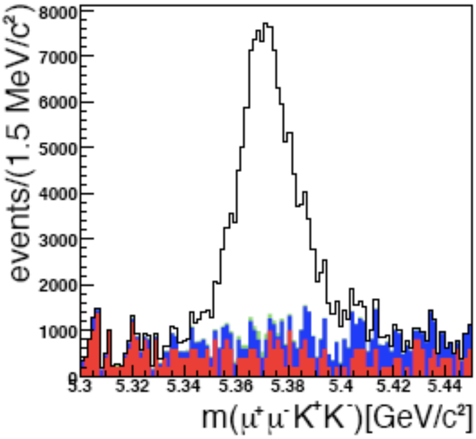

FIGURE 2. Bs invariant mass after cuts: The backgrounds are from inclusive $b \to (J/\psi)X$ (red), $B_d \to (J/\psi)K^*$ (blue) and combinatorial signal events (green).

TABLE 1. Results of the maximum likelihood fit for integrated luminosity of 1.3 fb^{-1} of signal and background at $\sqrt{s} = 14$ TeV

Parameter	Result	Stat. error	Total error
$[A_0(0)]^2$	0.582	0.006	0.0163
$[A_{\|\|}(0)]^2$	0.213	0.008	0.0099
$[A_\perp(0)]^2$	0.205	0.007	0.0118
$\bar{\Gamma}_s$	0.7060 ps^{-1}	0.0080 ps^{-1}	0.0240 ps^{-1}
$\Delta\Gamma_s$	0.1437 ps^{-1}	0.026 ps^{-1}	0.0279ps^{-1}
$\Delta\Gamma_s/\bar{\Gamma}_s$	0.204	0.037	0.041

Likelihood fit

The differential decay rate can be expressed as:

$$\frac{d^4\Gamma(B_s(t))}{d\Theta dt} = f(\Theta,\alpha,t) = \sum_{i=1}^{6} O_i(\alpha,t).g_i(\Theta), \tag{2}$$

indeed O_i are kinematics-independent observables and g_i the angular distributions. the symbol α represents the set of physical parameters $(\Gamma_L,\Gamma_H,[A_0],[A_{||}],[A_\perp],\delta_1,\delta_2,\phi_s)$, Θ represents the decay angles which define the kinematics and t is the proper decay time [7].

By applying an unbinned maximum likelihood fit it could be derived the parameters of the B_s system shown in Table 1.

Due to the tight selection criteria, the background rate is very small. This was verified by considering the following background processes:

1. $B_d \to (J/\psi)K^*$ decay,
2. $b \to (J/\psi)X$ decay,
3. direct (J/ψ) production

CONCLUSIONS

Prospects for an analysis of B_s to (J/ψ) decaying into two muons and ϕ decaying into two Kaons events with the CMS detector at LHC have been studied. This decay channel permits the study of different properties of the B_s system such as the width difference $\Delta\Gamma_s$ between the light and heavy mass eigenstates of the B_s, and the CP violating phase ϕ_s. The width difference between the weak eigenstates can be determined with a statistical uncertainty of 0.0011 with 1.3 fb^{-1} of Monte Carlo signal and background of simulated data. Assuming a width difference of 20%, an uncertainty of 4% is expected for an integrated luminosity of 1.3 fb $^{-1}$.

REFERENCES

1. C. Amsler *et al.*, *"Mechanical Design and Material Budget of the CMS BarrelPixel Detector,"* doi:10.1088/1748-0221/4/05/P05003, 2009.
2. A. Lenz and U. Nierste, *"Theoretical update of Bs-Bs-bar mixing,"* arXiv:hep-ph/0612167v3, 2007.
3. Alexander Lenz, *"Mixing and lifetimes of b-hadrons,"* doi:10.1063/1.2965074, 2008.
4. The UTfit Collaboration, *"First Evidence of New Physics in b-s Transitions,"* arXiv.org:0803.0659, 2009.
5. V. Ciulli *et al.*, *"Study of the decay $B_s \to (J/\psi)\phi \to \mu^+\mu^-K^+K^-$,"* CMS Note 2006/121, 2006.
6. Particle Data Group Collaboration, C. Amsler *et al.*, Physics Letters B667. doi:10.1016/j.physletb.2008.07.018, 2008.
7. L. Wilke, *"Study of the B_s-Meson with the First LHC Data,"* PhD thesis, Zurich University, 2009.